Segregation effects in processes handling powder mixture

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The handling of particles is a general operation concerning a great number of industries for which a process implies a treatment of matter or material: foods, pharmaceutical, cosmetics, chemical. This represents 60-70% of the processes. The materials can be of any type, mineral, organic.

The handling of materials is just a transfer from a place to another one, thanks to different devices by operating under different conditions.

This insures the transfer of particles from trucks to a bin or from a bin to the unit where the transformation of particles will occur, for example from mixer to bin, or bin to die where compaction or tabletting will occur, or bin to bags.

Generally speaking a process can be described through a series of operation units allowing the suitable transformations, like elaboration of particles by crystallisation, heating, melting, sintering or formulation by mixing of particles, leading to the material presenting the properties satisfactory for the end-user.

Unfortunately handling particles is not considered as a unit operation: nothing is intentionally done to change the material so that one supposes that nothing bad can happen. In particular the storage of particles that could appear as a totally neutral operation may be completely neglected by engineers searching causes of a variability in the properties of a product.

Nevertheless the powders handled in industries present quite different behaviours, depending on the characteristics of the particles themselves or the conditions under which they are used. In particular the segregation of particles, i.e. the spatial separation of particles making the granular medium composition not homogeneous is a phenomenon largely encountered.

A review of the main mechanisms of segregation will be given and the effects of both parameters –particle characteristics and conditions- upon the segregation of particles will be examined. Some examples from laboratories experiments and industrial problems illustrate the difficulties encountered by engineers to control and avoid serious inconveniences occurring in processes.

Among the different parameters characterising the particles, the one exhibiting the strongest influence in this kind of problem is the size, represented by the radius R of the sphere equivalent to the particle. The particle size distribution is one of the keys for the knowledge. A second is the adhesion energy Wa between a wall and a particle or the cohesion energy Wc between two particles. The particle shape and density can be also related to segregation effects. Of such effects, size difference is by far the most important, and almost always this is the most serious cause of segregation. In comparison the other effects are minor and unimportant (1).

The key parameters for the external parameters defining the storage conditions are mainly the temperature or relative humidity controlling the surface properties, and adhesion or cohesion. The geometrical parameters defining the shape and dimensions of the storage devices like silos are very often calculated in order to optimize the solution to flow problems: arching, piping, or segregation due to particle size. In addition mechanical energy can be also considered to facilitate inlet or outlet operations.

For these reasons, the studies must take into account two main types of powders: cohesive or free flowing particles (2). A given powder can exhibit a cohesive behaviour whenever its radius is lower than a critical one Rc, or a free flowing behaviour for R>Rc. The critical radius Rc depends on the particle interactions and the particle density.

A great number of experiments and discussions have been devoted to segregation effects in particle mixtures. Anyway the understanding of segregation is not achieved at all, even if a series of models allows some guide for interpretation.

Hereafter let us consider the main mechanisms of segregation.

A first type of segregation appears in particulate systems where the particles can behave without grain-grain interactions, i.e. in lean phase systems. **The segregation by projection, elutriation, or decantation** is the result of the forces exerted on the particle – gravity, drag, friction and driving forces.

This may yield opposite results: in air without a driving stream imposed to a particle, a small particle will be stopped very quickly after being projected from a gun. Whereas when a laminar gas flow acts continuously on small and large particles, the small particle will go further than a large one. Such size dependent movements can be also at the basis of particle size determination: sedimentation, fluorometry in lab, gravitational separation units in industry.

Other segregations take place in dense phase systems for packing with a packing fraction greater than 0.2.

the segregation by sifting corresponds to screen effects and may be observed when pouring a heap. Large particles run down to the edge of the heap and small particles remain in the middle: small particles are more easily stopped when going down the heap because big particles offer a higher barrier and trapping sites for small particles, and the rotational or translation kinetic energy of small particles is not enough to let them go further.

In the shear segregation, the percolation of small particles through a granular packing is created by shear stresses imposed to the bed. In this case, some mobility can be bring to the particles by an external device (drum shaker for example) and if a velocity gradient is set up any one layer of particles have a velocity relative to a neighbouring layer. If an opportunity is presented, particles can roll or percolate into a new layer. In fact smaller particles have a greater mobility because they need smaller sites in the adjacent layer, and segregation can take place. Such velocity gradients can be seen in milling or mixing operations in drums: 2D experiments show that small particles appear in the centre band of the bed and large particles stay around them (radial segregation). 3D experiments can also give sometimes another spatial separation, in the axial direction of the cylindrical drum, with alternate bands of the different kinds of particles.

In the **segregation due to vibration**, percolation of small particles downside through a granular packing can undergo also almost spontaneously if the ratio of the large on small particles is greater than 6, or it may be created by vibrations. This can be evidenced by the experiment in which a large and dense ball is placed at the bottom of smaller sand particles: after vibrations or shocks it will rise to the top surface after a few seconds.

The segregation effects can be characterised by two indexes: the intensity and the scale of segregation defined as well in mixing studies. The first expresses the composition variation from a segregated region to a region having the mean composition; the second indicates the length -or volume- separating the domains unmixed, each having a given composition.

They mainly depend on the powder properties that can be precised through laboratory tests like volumenometry, angle of repose, shear cell, image analysis, granulometry…

Of course these effects of segregation and transformation of particle-particle interactions can modify the composition of the granular media before, during or after the storage and transfer operations.

For storage or feeding applications two kinds of systems can be considered: lean phase flow or dense particle flows, corresponding respectively to industrial pneumatic conveying of particles dispersed in a gas flow of high velocity - with small concentration of solids-, or screw conveyors, belt feeders, volumetric proportioning equipments, plug conveyance – dense phase conveying systems-. As seen before, some relevant difficulties can be encountered linked to segregation effects.

In silos or hoppers for example, the user is always in front of a squeeze: to discharge a silo, discharge aids are intended to improve the bulk solid flow and draw the bulk solid out of the discharge outlet. For that purpose, pneumatic or mechanical devices (air injection, stirrers), vibrations by shakers or flow agents can be added. In the same time possible segregations might appear.

Vibrating conveyors are not suited for easily fluidisable solids.

The storage in a bin can be affected by the vicinity of external sources of vibrations.

References:

(1)Mixing in the process industries, Ed. N. Harnby, M.F. Edwards, A. W. Nienow, Butterworth Heinemann, Oxford, 1997, p.12

(2) Handbook of powder technology, Ed. D. Chulia, M. Deleuil, Y. Pourcelot, Elsevier- Amsterdam, 1994, vol. 9, p. 288.